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**Principal Investigator: H. A. Haus**

**in cooperation E. P. Ippen**

**Title: Interferometric Measurement with Squeezed Light**

The MIT effort in squeezing concentrates on the pulse excited Sagnac fiber loop reflector first proposed in 1989<sup>[1]</sup>. This scheme has the advantage of reusing the pump as the local oscillator. The first results on squeezing<sup>[2]</sup> were achieved in a fiber with exceptionally low noise caused by Guided Acoustic Wave Brillouin Scattering (GAWBS); i.e. index fluctuations caused by thermally excited acoustic waves which change the phase of the wave propagating through the fiber. For some very narrowly defined fiber parameters it is possible to distribute the acoustic resonances so that they do not convolve into the (low-) frequency range of the measurement window (40-90 kHz), for pulses of 100 MHz repetition rate (the rate generally produced by modelocked laser sources). It so happened that the fiber used met these exceptional conditions. Since these conditions are not easily met, it is important to develop techniques that suppress the GAWBS noise. The GAWBS spectrum "rolls off" before it reaches 1 GHz. Thus, if the pulse repetition rate is 1GHz or higher, the convolution of the GAWBS noise into the low frequency measurement window can be avoided entirely.

K. Bergman demonstrated the suppression of Guided Acoustic Wave Brillouin Scattering (GAWBS) in her squeezing experiments in fiber Sagnac rings, by developing a low noise Nd:YLF modelocked laser source modelocked at 1 GHz. The components for the laser were supplied by Spectra Physics free of charge in exchange for the information on the operating characteristics of the system. Spectra Physics is considering the development of the source into a commercial product. Bergman was able to obtain noise levels 5.1 dB below shot noise. The power of this method is that it can be used in any pulsed system subject to GAWBS, as long as the detection window is limited to low frequencies<sup>[3]</sup>.

Investigation of the parameters of the system has demonstrated that the amount of shot noise reduction is consistent with the system parameters. In fact, the peak of the gaussian pulse experiences 13 dB of squeezing, but due to the averaging of the squeezing upon detection, and the imperfect quantum efficiency of the detector, the shot noise reduction is limited to 5.1 dB. Theoretical studies have shown that with pulse preshaping<sup>[4]</sup> the shot noise reduction can be improved.

We have carried out a careful investigation of the Raman noise effect on squeezing.

Raman noise is somewhat analogous to GAWBS, except for the fact that the index fluctuations are induced by optical phonons rather than acoustic ones. Thus, it is a broad-band noise that does permit reduction or elimination by the schemes proven successful in the case of GAWBS. Previous investigators have concluded<sup>[5]</sup> that the noise does not affect squeezing appreciably at presently achieved levels (5 dB shot noise reduction) and that it is pulse-width independent. Our analysis is based on new careful experiments of the silica fiber Raman gain near zero frequency offset. One finds that the gain does not rise linearly as a function of frequency offset. The consequence is that the noise is not pulse-width independent, but rather increases with decreasing pulse-width, suggesting that for pulses shorter than 1 ps the Raman noise may become important.

Since squeezed radiation quickly degenerates through loss, it is important to use it in systems that, in principle, are loss-free for the squeezed radiation. Conventional fiber gyro designs do not have this property and hence modified designs have to be used. In the search for such a modified design, C. Doerr and Dr. Shirasaki, a visitor from Fujitsu, have arrived at a design which not only satisfies this criterion, but has several other unique properties that promise to lead to an improvement in conventional fiber gyro performance. Its advantages are

- (a) Conventional fiber gyros bias the Sagnac fiber loop with a nonreciprocal phase shifter, or through modulation of the input excitation. The new design biases via a simple reciprocal wave plate.
- (b) The design is insensitive to "drifts" in all elements to first order.

The gyro has been built and tested and all indications are that it will live up to its promise.

The analysis of squeezing calls for an accurate quantum theory of nonlinear optical systems. The excellent agreement between theory and our experiments suggest that the theoretical analysis of single-mode quantum processes developed by us and others is a reliable description of a class of such processes. Every measurement of an optical observable involves a nonlinear process. Hence the theory developed in connection with squeezing can be applied to long-standing questions of the theory of quantum measurement. One of these questions is as to the evolution of the wave function of a system subjected to a measurement. The postulate of van Neumann as to the "collapse of the wave function" upon a measurement can be explored in detail. It turns out that the collapse is an extreme form of a measurement in which perfect accuracy is achieved. Most measurements are not of this character and must be treated differently. The quantum formalism developed for nonlinear optics enables one to characterize such more general, and more realistic, measurements<sup>[6]</sup>.

## References

- [1] M. Shirasaki, H. A. Haus, and D. L. Wong, "Quantum theory of the nonlinear interferometer," *J. Opt. Soc. Am. B* **6**, 82-88, Jan. 1989.
- [2] K. Bergman and H. A. Haus, "Squeezing in fibers with optical pulses," *Opt. Lett.* **16**, 663-665, May 1991.
- [3] K. Bergman, H. A. Haus, E. P. Ippen, and M. Shirasaki, "Squeezing in a fiber interferometer with a GHz pump," *Opt. Lett.* **19**, February 1994
- [4] C. R. Doerr, F. I. Khatri, and M. Shirasaki, "Simulation of pulsed squeezing in optical fiber with chromatic dispersion," *J. Opt. Soc. Am. B*, January 1994.
- [5] J. K. Bounds and H. A. Haus, "Quantum noise of Raman amplification," *J. European Opt. Soc.*, accepted for publication.
- [6] F. X. Kärtner and H. A. Haus, "Quantum nondemolition measurements and the collapse of wave function," *Phys. Rev. A*, to be published.

## Publications and Meeting Papers

- 1. K. Bergman, C. R. Doerr, H. A. Haus, and M. Shirasaki, "Sub-shot-noise measurement with fiber-squeezed optical pulses," *Opt. Lett.* **18**, 643-645 (1993).
- 2. K. Bergman, H. A. Haus, E. P. Ippen, and M. Shirasaki, "Squeezing in a fiber interferometer with a GHz pump," *Opt. Lett.* **19**, to be published.
- 3. L. Boivin, F. X. Kärtner, and H. A. Haus, "Integrable quantum theory of self-phase modulation with finite response time," *Phys. Rev. Lett.*, forthcoming.
- 4. J. Bounds and H. A. Haus, "Quantum noise of Raman amplification," *JEOS Part B: Quantum Opt.*, to be published.
- 5. H. A. Haus and F. X. Kärtner, "On the theory of quantum measurement," paper presented at *Proceedings of the Third International Workshop on Squeezed States and Uncertainty Relations*, 1993.
- 6. F. X. Kärtner, D. Dougherty, H. A. Haus, and E. P. Ippen, "Raman noise and soliton squeezing," *J. Opt. Soc. Am. B*, to be published.

7. F. X. Kärtner and H. A. Haus, "Quantum-mechanical stability of solitons and the correspondence principle," *Phys. Rev. A* **48**, 2361-2369 (1993).
8. F. X. Kärtner and H. A. Haus, "Quantum nondemolition measurements and the 'collapse of wave function,'" *Phys. Rev. A* **47**, 4588-4592 (1993).
9. I. Lyubomirsky, M. Shirasaki, F. X. Kärtner, and H. A. Haus, "Test of Bell's inequality with squeezed light from Sagnac fiber ring," *JEOS Part B: Quantum Opt.*, **5**, 241-250 (1993).
10. M. Shirasaki, I. Lyubomirsky, and H. A. Haus, "Noise analysis of Mach-Zehnder squeezer for nonclassical input state," *J. Opt. Soc. Am. B*, to be published.
11. M. Shirasaki, I. Lyubomirsky, and H. A. Haus, "Phase correlation of Mach-Zehnder squeezer outputs for number state input," paper presented at International Conference on Lasers'93, Lake Tahoe, NV, December 6-10, 1993.

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